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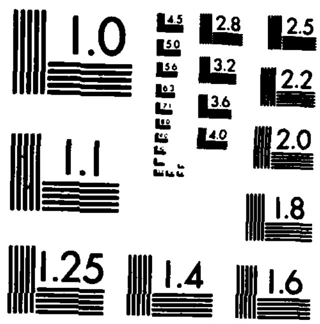

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WALL EFFECTS ON COMBUSTION IN AN ENGINE

FINAL REPORT

15 March 1983 - 14 May 1984

to

U.S. Army Research Office

Research Triangle Park, NC 27709

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This project utilized theoretical modeling and laboratory experiment to elucidate the role of chamber shaping on the combustion event in a four-stroke-cycle, reciprocating-piston-type internal-combustion-engine cylinder. Two specific topics were examined.

First, theoretical modeling was carried out to evaluate heat transfer as a determent of end-gas knock during nonisobaric flame propagation across a homogeneous charge in a variable-volume enclosure. Via a semi-empirical model, turbulent combustion in an automotive cylinder was considered; a three-zone generalization (to encompass end gas, unburned bulk gas, and burned gas) of the standard two-zone Otto-cycle-combustion model was developed. Via a selfcontained model, laminar combustion in a specially designed rapid-compression machine was considered; an asymptotic analysis valid in the limit of large Arrhenius activation temperature was developed. For given operating conditions, the fraction of the charge (if any) that undergoes autoconversion to product prior to flame arrival can be ascertained, along with the heat transfer sufficient to preclude such (over)

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19. ABSTRACT (Continued)

homogeneous explosion. Because of uncertainties in modeling of heat transfer, the procedures seem of more value in comparing propensity to knock for different operating conditions, and in comparing heat-transfer requirements for alleviation, than in establishing absolute values.

Second, two-wall, or crevice-type, quenching of flame propagation through a stoichiometric or fuel-lean hydrocarbon-air-type premixture is examined because this phenomenon is now believed to be the major source of unburned-hydrocarbon emissions from homogeneous-charge engines. Both quasilinearization/ADI numerical integration of a two-dimensional elliptical formulation of the eigenvalue problem for flame speed, and also laser-Raman-spectroscopy probing of a flame which is stabilized on a heat-sink-type burner and which lies between parallel impervious noncatalytic sidewalls, are used to characterize how the critical (quench) separation decreases as duct-wall temperature increases.

FOREWORD

The participants are grateful to the technical monitor of this project, David Mann, for encouragement, insight into Army technical requirements in automotive engines, and information concerning related Army-sponsored research.

The participants are also grateful to Ann McCollum for the preparation of the technical manuscripts prepared during this contract, and to Asenatha McCauley for preparation of the technical drawings.

SUMMARY

This project was concerned with theoretical modeling and laboratory experiment to elucidate the role of chamber shaping on the combustion event in a four-stroke-cycle, reciprocating-piston-type internal-combustion engine.

First, modeling of heat transfer as a determent of end-gas knock in a homogeneous-charge engine was undertaken (Carrier, Fendell, Fink, and Feldman 1984). The last portion of the charge to be burned is subject to the greatest compressional heating owing to the expansion of the hot, already burned gas. This portion of the charge may undergo autoconversion to product prior to arrival of the propagating flame. The consequence of the very rapid, constant-volume, spatially homogeneous autoconversion is engendering a nonlinear pressure wave, whose interaction with cylinder component results in audible knock. The autoconversion is particularly likely in high-compression-ratio engines of large bore under sudden acceleration. Under such operation, the combination of large spark advance, low engine speed, and large cylinder mass results in long flame transit time and increased opportunity for explosion in the highly preheated end gas. Analysis to indicate what fraction (if any) of the charge might undergo autoconversion, and what heat transfer from the end gas would preclude this autoconversion, has been carried out by generalization of the well-known two-zone approach to combustion-event modeling in a homogeneous-charge engine. The work corroborates that increased surface-to-volume ratio along the flame path can inhibit knock without incurring unacceptably thick quench layers. (The alternative approach is identification of an economically and environmentally acceptable replacement for tetraethyl lead as a knock-inhibiting fuel additive; chemical-kinetic investigations have yet to identify such an additive.)

The above-described engine-cylinder work does require as empirical input the turbulent flame speed. A selfcontained analysis pertinent to the well-known laboratory simulation device known as a rapid-compression machine also has been carried out (Bush, Fendell, and Fink 1984). For the laminar-like conditions of some rapid-compression machines, e.g., the so-called CE-1 device in the Mechanical Engineering Department of the University of California, Berkeley, the flame propagation rate may be deduced from a chemical-kinetic model. The main challenge is that the relatively thin flame front, separating polytropically compressed burned and unburned portions of the charge, necessitates introduction of

multiscaling techniques. However, the device offers a far more accessible quantitative description of how parametric changes alter knock propensity during nonisobaric combustion in a variable-volume enclosure. While the analysis is based upon a spatially homogeneous, though temporally varying, pressure--so that the model is inappropriate beyond the onset of knock--still, if knock intensity can be related to mass of charge that undergoes autoconversion, then the analysis gives insight on knock intensity as well.

Another line of activity concerned experimental (Fairchild 1984) and theoretical (Carrier, Fendell, and Feldman 1984) investigation of two-cell, or crevice-type, quenching of flame propagation. This type of quench (as opposed to one-wall quenching) now is widely accepted to be the major source of unburned hydrocarbon emissions from homogeneous-charge engine cylinders. If heat loss from hot product gas to close-by, relatively cold walls precludes preheating of fresh charge to its ignition condition, then flame propagation is precluded. A counterstrategy is to reduce heat transfer to the walls by allowing the temperature of the walls to rise, so that flame propagation can persist into a smaller crevice. This concept can be investigated in the laboratory by use of nonintrusive laser-powered optical diagnostic techniques (especially laser Raman spectroscopy). In particular, a planar fuel-lean premixed flame of simple hydrocarbon and air is stabilized on a heat-sink-type, porous-sintered-bronze flameholder. Two parallel planar water-cooled walls are sited flush against, and perpendicular to, the exit face of the flameholder (Botha-Spalding burner). As the two walls are brought into closer proximity, the quenching distance is identified (as a function of wall temperature--and many other parameters). The problem of optical access is resolved by careful geometric design. The theoretical counterpart involves using quasilinearization/ADI numerical integration of a two-dimensional elliptical formulation of the eigenvalue problem for flame speed. Again, the objective is to identify how the flame speed (the eigenvalue) decreases (and, at some finite separation, abruptly vanishes) as a function of wall temperature. A particular difficulty is how to introduce (in a multidimensional flow) an ignition temperature in a physically meaningful way, in order to handle the so-called cold-boundary difficulty, whereby a premixture at any finite temperature undergoes reaction prior to flame propagation. A significant

reduction in quench distance seems achievable if the wall temperature is increased from ambient by (say) twenty percent of the increment of adiabatic flame temperature over cold premixture temperature.

PUBLICATIONS

Bush, W. B., Fendell, F. E., and Fink, S. F. (1984). Modeling end-gas knock in a rapid-compression machine. AIAA J., in review. [Presented as AIAA paper 84-0208, 22nd Aerospace Sciences Meeting, January, 1984 (held at the MGM Grand, Reno, Nevada.]

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Carrier, G. F., Fendell, F. E., and Feldman, P.S. (1984). Laminar flame propagation/quench for a parallel-wall duct. Twentieth Symposium (International) on Combustion, to appear. Pittsburgh, PA: Combustion Institute. [To be presented at the symposium of the Combustion Institute, University of Michigan, Ann Arbor, August, 1984.]

Fairchild, P. (1984). Parametric studies of crevice quench by laser Raman spectroscopy. Twentieth Symposium (International) on Combustion, to appear. Pittsburgh, PA: Combustion Institute. [To be presented at the symposium of the Combustion Institute, University of Michigan, Ann Arbor, August, 1984.]

APPENDIX

List of Technical Participants

William Bush*	(asymptotic analysis)
George Carrier*	(approximate analysis)
Paul Fairchild	(optical physics)
Phillip Feldman	(numerical analysis)
Francis Fendell†	(approximate analysis)
Stanton Fink	(numerical analysis)

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*Consultant to TRW; not funded under contract.

†Principal investigator.